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ON THE OPTICAL IDENTIFICATION OF THE VELA PULSAR

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ABSTRACT

We present the results of attempts to find the optical counterpart of the radio pulsar PSR 0833−45 in Vela. The observational material consists of phase-selective image-tube photographs of the field surrounding the radio position of this pulsar and a time-averaged summation of the photographic material. Attention is called to a faint star near the radio position of the pulsar, and an improved upper limit is derived for pulsed optical emission.

I. PHASE-SELECTIVE OBSERVATIONS

An area of approximately 20 square minutes of arc centered on the radio position of pulsar PSR 0833−45 in Vela was studied by means of phase-selective photography on 1970 January 9–12 (U.T.). The observations were made with the Pulsar Hunter (Chiu, Lynds, and Maran 1970) attached to the 60-inch telescope of the Cerro Tololo Inter-American Observatory. The Pulsar Hunter consists basically of an image intensifier and a synchronous shutter mechanism that permits photography during discrete phase intervals with reference to a particular clock frequency—in this case, the same as the pulsar frequency. The image tube used, a Westinghouse W-30677, has an S-25 photocathode; all photographs were made without a filter and were of 10 minutes duration. Because the phase resolution of the observations (i.e., the duty cycle of the shutter) was 0.05, the net exposure of each plate was 30 seconds. Under ideal conditions, such exposures should record stars to approximately magnitude 22. On January 8, the known optical pulsar NP 0532 in the Crab Nebula was observed in order to verify that the apparatus was operating properly.

Although the phase resolution of each plate was 0.05, the interval between the central phases of successive exposures was slightly smaller than this value, in order to provide some overlap. On January 9, 10, and 11, the interval was 0.0469, so that twenty-two exposures were required on each of these nights in order to provide full coverage. On January 12, the interval was 0.0438, so that twenty-three exposures were needed. The attempt on January 9 was unsuccessful; only eighteen plates were obtained, and they were of uneven quality, with the limiting magnitude ranging from 20 to nearly 22. The second night was more successful; twenty-nine plates were obtained with sufficient overlap in phase that an entire cycle was covered. Because of variable conditions and instrumental difficulties, these photographs were not of equal quality; half of the material

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reached a limiting magnitude of 21.5, while the remainder reached only 21.0. The quality of the twenty-five photographs obtained on the third night was somewhat more uniform; two-thirds of the cycle was covered to 21.5, with the remainder going to 21.0. On the last night, twenty-nine plates cover most of the phase intervals to magnitude 21.5; but for two phase intervals the field is represented to only 21.0.

Although the quality of the photographic material obtained falls somewhat beneath the capabilities of the instrument, the field of the pulsar has been observed throughout the entire cycle of variation, and we conclude that an optical pulsar has not been missed if it was as bright as 21.0 during an interval of 0.05 in phase. During most of the cycle of variation, a pulsar reaching magnitude 21.5 would probably not have gone unnoticed. The time-averaged magnitude of such a pulsar would be about 24.8, provided that its duty cycle was about 5 percent.

One possible candidate was found in the field when the phase-resolved plates were examined. However, an image of the hypothetical object was recorded on only two plates, and these two plates were separated by 0.09 in phase, with no evidence for the object on the intervening plate. Sections of the two plates showing the candidate object are reproduced in Figure 1 (Plate L1). If this candidate is real, it reaches approximately magnitude 21 in what appears to be a double pulse. This would be only marginally consistent with the photoelectric limits (Kristian 1970). We adopt $\alpha(1950) = 08^h33^m39\overset{s}{.}09 \pm 0\overset{s}{.}05$, $\delta(1950) = -45°00'05\overset{''}{.}3 \pm 0\overset{''}{.}02$ (G. S. Downs and P. E. Reichley, private communication) as the radio position of the pulsar. The position of the optical object is in agreement with this radio position in right ascension but is 8″ too far north, which is of the order of 40 σ away from the radio position.

It is possible that this candidate object is not real and is a flaw of instrumental origin. A number of suspected flaws of similar appearance were noted during the inspection of the photographic material; however, these were sufficiently infrequent that the occurrence of a flaw at exactly the same position on two plates is something of a surprise. Another possible explanation for the images is that there is at the position a faint star that is generally at or below the photographic limit of the present material, although this does not appear likely when one notes the relative prominence of the images in Figure 1.

As a more critical test of this possibility, we superimposed seventy-five of the best photographs—not including those showing the possible candidate—to form a composite picture that goes to a considerably fainter limiting magnitude than any individual plate. This composite photograph is reproduced in Figure 2 (Plate L2); the magnitude limit is estimated to be approximately 23. It is seen that, although the composite photograph has reached a considerably fainter limiting magnitude, there is no evidence for a star at the position of the candidate object.

Although this pulsar candidate cannot be completely discounted, it is our opinion that the images are probably not real and that the identification is not valid. The principal reasons are: (*a*) the position of the candidate disagrees with the radio position, (*b*) the photograph intervening in phase between the ones showing the candidate does not appear to be especially inferior in sensitivity and yet does not show any evidence of an image of the object,[1] (*c*) flaws resembling star images are not unknown on the photographs, and (*d*) there is little or no evidence for the presence of images of the candidate object on any of the other plates.

The observational limit on brightness variations in the eighteenth-magnitude star advanced as a candidate by Cocke, Disney, and Westerlund (1969) is about 0.5 mag, as derived from the Pulsar Hunter photographs. Stricter limits on pulsations of this star can be derived from the photoelectric data (Freeman *et al.* 1969; Hesser *et al.* 1969; Kristian 1970; Warner and Nather 1969; Willstrop 1969).

[1] The pulse does appear to be double at higher radio frequencies (Gardner and Whiteoak 1969; Downs 1969), but the separation is 2 msec, rather than the 9 msec that would be required here.

II. DISCUSSION OF THE COMPOSITE PHOTOGRAPH

The foregoing discussion has been largely predicated on the assumption that any optical counterpart to the Vela pulsar will behave like the Crab Nebula pulsar NP 0532, i.e., that its optical pulses will be similar to its radio pulses. This need not be the case, and lines of evidence not based on optical variability may prove to be important in making the correct identification. At present, the only other evidence consists of positions of optical objects with respect to the very accurate radio position of the pulsar.

The optical position of the candidate of Cocke *et al.*, which is a useful reference point, has been measured by Kristian (1970) as $\alpha(1950) = 08^h33^m38^s.34 \pm 0^s.05$, $\delta(1950) = -45°00'01''.9 \pm 0''.5$, which is 7″ west and 3″.4 north of the radio position. The composite photograph of Figure 2 shows a faint star 6″ east and 2″ south of the object of Cocke *et al.*, and this faint star (magnitude about 22) is not far outside the combined radio and optical errors. Although the star is not recorded with certainty on most of the plates, its apparent brightness on the composite photograph rules out a photometric variation as extreme as that of NP 0532, as do the photoelectric measurements. This is the only candidate plausibly near the radio position down to the magnitude limit (≈ 23) of the composite photograph.

Finally, Cocke *et al.* mention the possibility of faint nebular wisps emanating from their candidate star. The composite photograph in Figure 2 shows no evidence of such wisps, although it presumably registers features to a much fainter limit. The nonuniformities that are seen elsewhere on the composite photograph are cosmetic defects of the image tube that are revealed by the greatly enhanced signal-to-noise ratio resulting from the superposition process.

III. CONCLUSIONS

The candidate of Cocke *et al.* does not now appear promising because it does not vary significantly and because of position disagreement (Kristian 1970). The candidate found on our phase-selective photographs does not appear promising because of position disagreement and because of the possibility that the recorded images are flaws. We advance as a new candidate the object near the radio position, detected on the composite of seventy-five Pulsar Hunter photographs. This object is interesting only because of the marginal position agreement; it is not noticeably pulsing at the radio period. Further observations are planned with an improved version of the Pulsar Hunter; phase-selective photometry that uses very small diaphragms should also be carried out.

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